

The Chehr Abad “Salt Men” and the Isotopic Ecology of Humans in Ancient Iran

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ABSTRACT We have carried out isotopic analysis ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) on five salt-preserved bodies from the salt mine at Chehr Abad, Iran, dating from the 4th C. BC through to the 4th C. AD. In an attempt to identify the geographical origins of these people, we have analyzed over a hundred archeological bone samples from various archeological sites in Iran. From the faunal remains, we observe that the entire ecosystem appears to be enriched in ^{15}N , which we suggest is due to the semi-arid nature of the region. We have also observed a number of cattle remains from one site (Nargas Tepe) which have a significant C_4 component to their diet from the 4th millennium BC. By combining our data

with those published by [Bocherens et al.: *Environ Archaeol* 5 (2000) 1–19; Bocherens et al.: *J Arch Sci* 33 (2006) 253–264], we suggest that two of the “mummies” may have come from the Tehran/Qazvin Plain region (i.e., relatively local to the salt mine), and a further two appear on isotopic grounds to have come from the northeast of Iran or the Turkmenistan steppes. The fifth (no. 4), the best preserved, appears to have come from further afield. Collectively, these mummies and their contexts augment our knowledge of social mobility and technical innovation in Iran during the Achaemenid period. *Am J Phys Anthropol* 143:343–354, 2010. © 2010 Wiley-Liss, Inc.

The Chehr Abad salt mine, near Hamzehloo in Zanzan Province, Iran, has produced some remarkable evidence for the extraction of salt from at least the mid-first millennium BC (Aali, 2005). In addition to the large quantities of textile, wood, and food remains from the site, five human “mummies” have been recovered. Three are largely skeletonized assemblages of partially articulated human bone (Mummies no. 2, 3, and 5), but with some soft tissue, hair, and teeth remaining. A fourth (Mummy no. 4) appears intact, and fully clothed. The first to be found (Mummy no. 1) is a well-preserved head (with hair) and a boot containing a lower limb, plus a further unsorted assemblage of mixed bone and artifacts. Three of the individuals (Mummies no. 3, 4, and 5) have been radiocarbon dated to between 410 and 350 cal BC, whilst Mummy no. 1 is more poorly dated, to between 220 and 390 cal AD, and Mummy no. 2 to between 430 and 570 cal AD (Pollard et al., 2008). The excavations carried out at the mine, and a preliminary report of the finds, are described in Aali (submitted).

Despite the importance of salt as a commodity in the ancient world, there is little excavated evidence for the collection and trade of salt. The only parallel for deep-mined salt anywhere in ancient Eurasia are the Iron Age salt mines at Dürrnberg in Austria (Boenke, 2005). Although roughly contemporary with the Chehr Abad mines, crucially these mines contain no human remains (other than coprolites)—perhaps a consequence of the relative lack of seismic activity in Europe. Therefore this assemblage from Iran is unique. The primary research questions to be addressed are “how was the site exploited—who was doing the mining, what was the socio-economic context of the mine, and where was the

salt traded?” There is ample evidence from the mine itself for salt extraction (pick marks, wooden spikes for splitting the rock, metal tools including handles, and even a leather sack containing large lumps of rock salt), and the injuries to the bodies so far ascertained (especially no. 4 and 5) are consistent with death from rock fall in the mine. It seems reasonable therefore to assume that these five bodies represent miners (or at least visitors to the interior of the mine) rather than burials placed inside the mine for whatever reason.

Amongst the botanical remains found during the excavation were acorn and dried medlar. These do not grow in the Zanzan area and must have been brought from other places. Acorns grow in the Zagros mountains in the west and south of Iran, and to a lesser extent in the north. Medlar is a fruit of the Caspian Sea region. Although all of the excavated material has yet to be

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studied in detail, based on a preliminary study, some of the pottery is comparable with assemblages from the west and north-west of Iran. The clothing of Mummy no. 4 is identified as being Median in style. The Median region in the Achaemenid era consisted of Azarbaijan, Zanjan, and Hamedān (in the north-west of Iran and to the west of the Caspian). It is also likely that the clothing of Mummies no. 3 and 5 is similar in style.

Thus an isotopic study of the human remains themselves could be a significant contribution to understanding who these miners were and where they came from. In a previous paper (Pollard et al. 2008) we presented some isotopic data from these remains, but unfortunately at that time there was very little isotopic data for other human remains from Iran, and none covering the same time periods as these “mummies.” Nor do we have much comparative faunal isotopic data from which to interpret these data. Most relevant is the work of Bocherens et al. (2000), with some modern and archeological data from three sites on the Qazvin Plain (Sagzabad, Qabrestan, and Zagheh), located between Zanjan and Tehran, and Bocherens et al. (2006), with data from southern Turkmenistan. By comparing the average values of the “salt men” with generic isotopic trophic level diagrams, we observed in Pollard et al. (2008) that these remains had higher $\delta^{15}\text{N}$ values than might be expected from a purely terrestrial C_3 -based diet, and speculated that they might not have been local to Zanjan province. From a more detailed comparison with the published data, we tentatively concluded that three of these mummies (no. 2, 3, and 5) had diets consistent with the more extreme values observed by Bocherens et al. (2000) in human remains of an earlier date from the Qazvin plain—i.e., they could have been relatively local. Mummy no. 4 (the most complete), however, appears to be isotopically significantly different, suggesting an origin with a substantial marine/freshwater input, possibly the Persian Gulf, or perhaps the large freshwater systems of the Caspian or Black Seas. Mummy no. 1 is also significantly different in $\delta^{13}\text{C}$ (the values measured in 1994 were: -16.4% for sample P5952 and -17.1% for P5953) but $\delta^{15}\text{N}$ was not measured at that time. Based purely on the available $\delta^{13}\text{C}$ values, we postulated a significant C_4 input into his diet. Since Bocherens et al. (2000) have reported the presence of C_4 plants in the area, this could still imply that he was local to the Qazvin Plain, but humans with this diet were not represented in the very limited human data then available.

We also noted in Pollard et al. (2008) that the fingernails of Mummy no. 4 showed no evidence of extensive manual activity, that both Mummies no. 1 and 4 had precious metal ear rings, that a sample of gut content from Mummy no. 5 showed a lack of intestinal parasites, and also that his hands appear to have been treated with some form of protective cream. All these points are perhaps indicative of a higher status than one would expect for professional or conscripted miners, and suggest that these three individuals, at least, may have been visitors who traveled to the mine on an occasional basis to collect salt. This is consistent with the view of the archeologists in the Zanjan Cultural Heritage Organization, who believe from field-walking around the mine site that there is no evidence for any local ancient settlement. It contrasts strongly with the evidence from the Greek world where, for the Lavrion silver mines at least, mines were worked by slave labor (Hopper, 1961), or by slaves, convicts and Christians in the Roman pe-

riod (Healy, 1978; p 132). Although these comparisons differ completely in terms of product and scale, the key question remains: “who were these people who died in the salt mine?” To put these preliminary conclusions onto a firmer footing, we therefore embarked on a more systematic study of the isotopic composition of human and animal bone from ancient Iran, and it is these data and comparisons that we present here.

MATERIALS AND METHODS

The samples

As part of the collaborative research project between the Oxford Radiocarbon Accelerator Unit and the Iranian Cultural Heritage, Handicrafts and Tourism Organization (ICHHTO), we have received a large number of bone samples for radiocarbon dating from various prehistoric sites in Iran (discussed below), and which we have now also used for isotopic measurements. The samples submitted consisted of a number of bags containing mixed unidentified bone fragments and charcoal from a single context within a particular site. On arrival each bag was given an identifier (a “P number”), and an identifiable fragment was selected for radiocarbon dating. We assume in this article that the date thus obtained for each context (P No.) is applicable to the samples selected for isotopic analysis, even though in the majority of cases it was not the same bone fragment that was dated. For the isotopic research, we selected bones which were identifiable to species from each context (sometimes selecting more than one sample per context if they were clearly from a different individual or species), and noting where the bone sampled for isotopic analysis was the same as had been sampled for dating. Supporting Information Table S1 (available online) lists the samples taken for isotopic analysis. Each sample is identified by a project number (of the form “Iran xx”), the name of the archeological site, the P number (i.e., the context), and the species and skeletal element sampled. Where possible we have recorded the uncalibrated radiocarbon date and error associated with samples from the same context, and have indicated by printing in bold where the radiocarbon date was obtained from the same bone fragment as was sampled for isotopic analysis. The OxA number is the unique identifier for each successfully-dated sample.

The sites

Most of the sites and samples were selected by members of ICHHTO and submitted to Oxford for dating as part of their ongoing research into the Late Neolithic to Early Chalcolithic (c. 6200–4000 BC) sequence of settlements on the Tehran Plain and elsewhere. They are not therefore geographically or temporally ideal for comparison with the later “salt men” of Chehr Abad, but they do provide the best material currently available for studying the isotopic ecology of humans and domesticated animals from ancient Iran. Figure 1 shows a map which locates the sites listed below. The approximate dates of occupation of these sites are shown in Figure 2, which summarizes the calibrated age ranges of dates obtained from these sites (unpublished ORAU dates). The sites from which the samples were submitted are as follows:

Gourab. The tell site of Tepe Gourab is located in the central Zagros of Iran in Hamadān province close to the



Fig. 1. Map of Iranian showing sites from which bone samples have been obtained (filled circles), and the location of the salt mine at Chehr Abad (star).

						Cal BC									Cal AD	
Site	Date	6000-5500	5500-5000	5000-4500	4500-4000	4000-3500	3500-3000	3000-2500	2500-2000	2000-1500	1500-1000	1000-500	500-0	0-500	500-1000	1000-1500
Gourab																
Hegmataneh																
Nargas Tepe																
Tepe Pardis																
Qaleh Khan																
Soha Chai Tepe																
Tepe Kelar																
Tubreh Riz																
Sagzabad (ORADS)																
Sagzabad (Bocherens)																
Qabrestan (B)																
Zagheh (B)																

Fig. 2. Calibrated age ranges of Oxford dates obtained from these sites (Oxford Radiocarbon Accelerator Unit, unpublished).

modern city of Malayer. The site was excavated in 2006 for the purpose of establishing the chronology by Ali Kaksar. The site has 26 m of cultural deposits ranging from the Middle to Late Chalcolithic, Bronze Age and

historical (Achaemenid) to the later historical period. The latest phase covers the Sassanian period. The 28 samples taken for isotopic analysis consists of sheep/goat (17) and cattle (10), plus one pig, from a range of con-

texts originally identified as Chalcolithic through to Bronze Age, and Parthian.

Hegmataneh. Hegmataneh (or Hekmataneh) is part of the ancient city of Ecbatana, the capital of the Median Empire (625 BC to 549 BC), and is located in the suburbs of modern Hamadān. According to Assyrian inscription it was founded in 1100 BC (but is undoubtedly older), became the Median capital, and was then one of the Achaemenid capitals (558 BC to 330 BC). It stands on the Silk Road. The area of the city which has been excavated so far is largely Parthian (247 BC to AD 224), and has been nominated for inscription as a UNESCO World Heritage site. Ten bone samples were taken; of which seven were sheep/goat, two cattle, and one pig. Recently Hegmataneh was excavated by Masod Azarnoush in 2007 and 2008 for chronological purposes and the new results indicate that the city plan of Hegmataneh belongs to the Parthian period.

Nargas Tepe. Nargas Tepe is located to the north of Gorgan city of Golestan province close to the Caspian Sea and the border with Turkmenistan. For rescue purposes the site was excavated in 2003 and 2005 by Gorbani Abbasi (2007). The site covers the main cultural periods of the Bronze and Iron Ages and also the Chalcolithic period. The excavations were mainly of the cemetery and the residential parts of the site. The 12 samples consist of six cattle, two equids, two sheep/goat, one deer, and one pig.

Joubaji Site, Rāmhormoz, Khouz. The site of Joubaji is located in the south west of Iran in Kuzestan province close to the city of Rāmhormoz. In the spring of 2007 the city council of Rāmhormoz excavated a water channel in the city suburb and discovered two royal tombs of the new Ilamid kingdom. Inside the two bronze coffins were the skeletons of two young women with many luxury goods. The samples consisted of one of these two humans and one sheep/goat.

Tepe Pardis. The site of Tepe Pardis on the Tehran Plain to the south-east of Tehran was identified as a Chalcolithic site by Mr. Naser Pazuki of the ICHTTO and visited by an Anglo-Iranian survey team in the summer of 2003. It has subsequently been excavated (Coningham et al., 2006; Fazeli et al., 2007; <http://www.dur.ac.uk/arch.projects/tehranplain/excavation.html>). Although Late Chalcolithic ceramics were identified in the exploratory survey, only pottery from the Late Neolithic, Transitional Chalcolithic, Early Chalcolithic, and Middle Chalcolithic were found in excavation, along with the substantial remains of pottery kilns. Sixteen of the 17 samples taken were human, and all date to c.1500 to 1400 cal BC. The other sample, which produced insufficient collagen for analysis, was equid.

Qal'eh Khān. Qal'eh Khān is in the north of Khorasan Province, in the north-east of Iran, close to the Turkmenistan border. It was excavated recently by Omran Garajin, with human skeletons dated to between 4400 and 4700 BC. The site mainly contains the cultural materials of the Late Neolithic and Chalcolithic periods. The aim of the excavation was to create a regional chronology. Omran Garajin excavated the site in 2006. The five samples consisted of four sheep/goat and one cattle.

Soha Chai Tepe. Soha Chai Tepe is located in Zanjan province between the Zagros and Alborz mountains. The site, which had a single period of occupation, was excavated by one of the authors (Abolfazl Aali) in 2005/2006

as a salvage project. It is a very small site (less than 500 m²) and seems to have been a temporary site. The cultural materials from the site indicate a high interaction with the communities of the central Zagros. The four samples consist of two equids and two sheep/goat.

Tepe Kelar. Tepe Kelar is in the Kelardasht region of Mazandaran Province, north of Tehran in the Alborz Mountains. The tell site of Tepe Kelar was excavated in 2006 and 2008 by Mousavi Kohpar in two seasons (Mousavi et al., 2007). The site size is 6 ha and the upper layers consist of the first millennium BC cultural context but the lower layers presented fourth and third millennium BC cultural layers.

Tūbreh Rīz. The site is located 9 km south of Kūdasht city in Lurestan province in the central Zagros. The tell site of Tūbreh Rīz was excavated by Pouria Kadish in 2007 for chronological purposes. The top layers of the site cover the Middle Islamic period but the lower layers consist of the prehistoric period. The 17 samples consisted of 10 sheep/goat, 2 humans, 2 equids, and 1 each of cattle, dog, and pig.

Lama cemetery. Lama Cemetery is located in Chal Shahin area in the township of Dena in Kohkiluyeh-va-Boyer Ahmad province. Some 53 graves were identified during archeological excavations in the year 2000 in this cemetery (Rezavani et al., 2007). Initial studies on the findings revealed that the graves must have belonged to 3500–3000 years ago. Ten samples of human bone were taken, but only two gave enough collagen for analysis.

Measurement procedure

Samples were superficially cleaned using an air-abrasive system with 5 μ m aluminum oxide powder. The bones were sampled by crushing 0.5–1 g of bone. Samples were dematerialized using 10-ml aliquots of 0.5 M HCl solution at 4°C. The acid was changed at 48-h intervals until no further reaction was seen. Samples were then rinsed three times with milli- μ ultra pure water then placed in 10 ml of pH 3 water at 75°C for 48 h. Samples were filtered using Eezee[™] filters. The supernatant liquid was decanted in nalgene[™] tubes with a temporary parafilm[™] cover. These tubes were then frozen in a liquid nitrogen bath prior to freeze drying in a Zirbus VaCo5 freeze drier fitted with an oil free vacuum system for 72 h or until no further weight loss was observed.

Purified collagen samples were then weighed out for analysis using c. 2.5-mg aliquots weighed into pre-cleaned tin capsules. Samples were combusted on a Carlo Erba 1108 elemental analyzer system using a helium carrier gas with a flow of ~80 ml per minute. A 2% split of the gases evolved was analyzed for nitrogen and carbon stable isotopic composition using a Sercon Geo-20/20 gas source mass spectrometer operating in continuous flow mode. Isotopic values as well as elemental abundances and carbon to nitrogen ratios were calibrated against an in-house alanine standard which itself is routinely measured against international standards whose values are traceable back to the VPDB international standard. Further aliquots of the alanine standard were used to monitor and correct for instrumental drift.

Where sufficient collagen was recovered samples were run in triplicate. Stable isotopic results are reported in delta notation relative to VPDB for carbon and AIR for nitrogen. Replicate analysis of the alanine in-house standard suggests that the values obtained during the

analysis reported here are accurate to $\pm 0.11\%$ for $\delta^{13}\text{C}$ and $\pm 0.4\%$ for $\delta^{15}\text{N}$ (82 measurements).

RESULTS

The results of the isotopic measurements from the human and faunal samples are listed in Supporting Information Table S1. The average percentage collagen yield from the 109 bones sampled was 7.4% (range 0–18.3%). In all, 14 samples (13%) were rejected on the

grounds of producing no (5) or too little collagen (9—in some of these cases sufficient collagen was produced, but the %N and/or the %C was too low, or the C/N molar ratio was not acceptable). The average %C in the collagen samples used was 42.3% (range 11.7–55%) and for %N 15.4% (range 3.9–20%). The average C/N ratio of the samples accepted was 3.23 (range 3.17–3.58; note: the figures for %C, %N, and C/N ratio are the averages of the replicate measurements made on the same sample of collagen for each bone—usually three). The majority of the samples which failed to produce sufficient collagen were human mandibles from Lama Cemetery. The average standard deviation of the triplicates for each sample reported here was 0.10‰ for $\delta^{13}\text{C}$ (range 0.01–0.3‰) and 0.31‰ for $\delta^{15}\text{N}$ (range 0.01–0.62‰). Figure 3 shows a plot of $\delta^{13}\text{C}$ vs. $\delta^{15}\text{N}$ for all these data coded by site.

Table 1 shows the isotopic data measured in Oxford on material from the five "salt men" preserved at Chehr Abad. Some of these measurements were published in Pollard et al. (2008). The bodies are numbered as in Pollard et al. (2008), and the dating of the bodies is discussed in detail there. The four measurements reported for Mummy no. 1 in that paper were made in Oxford in 1994 in support of the radiocarbon dating of this body, using samples submitted by ICHTO, and at that time $\delta^{15}\text{N}$ was not routinely measured. Because of the nature of the recovery of this body (discovered by mechanical excavation: see Pollard et al. 2008) there is no certainty that these four objects are related, and there is even some doubt as to whether the leg belongs to the same body as the head (we assume that one of the bone samples in Table 1 is from the head and the other is from the leg, but we now have no record as to which is which). The two measurements reported in Table 1 for the bone samples from Mummy no. 1 are remeasurements made in 2009 on archived samples of collagen from the original radiocarbon samples. Sample P5952 was reprecipitated to produce a cleaner sample, but otherwise the measurements were made (in triplicate) as described above. Similarly, all of the measurements on

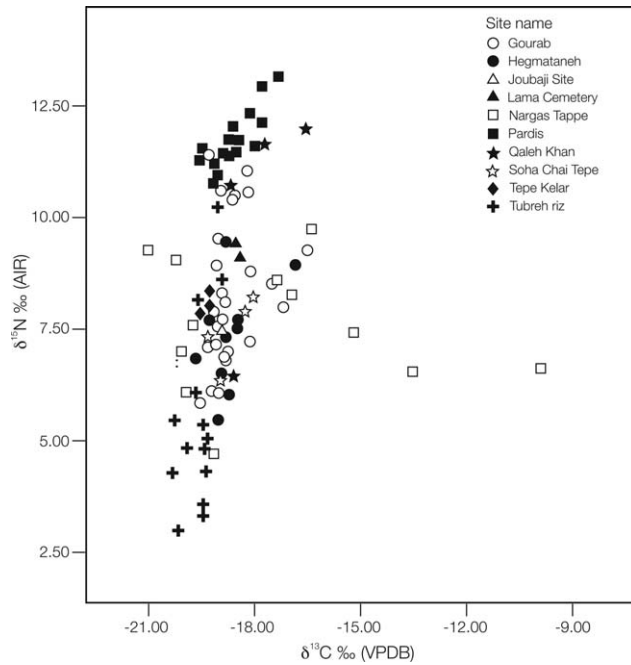


Fig. 3. Isotopic plot of $\delta^{13}\text{C}$ vs. $\delta^{15}\text{N}$ for all the Oxford data coded by site.

TABLE 1. Isotopic data on "Salt Men"

Sample id	Mummy no.	Species	P no.	OxA	Material	% yield	%C	%N	C/N	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$
SM1.1	1	Textile	5950	4812	wool?	48.4	41.2			-20.6	
SM1.2	1	Textile	5951	4813	wool?	43.8	40.4			-20.9	
SM1.3	1	Human	5952	4814	bone	7.5	44.0	15.14	3.39	-18.07	12.87
SM1.4	1	Human	5953	4815	bone	6.7	45.0	16.16	3.24	-17.73	12.60
SM2.1	2	Human	15222	17112	soft tissue	2.6	46.1		4.59	-20.3	13.7
SM2.2	2	Leather	15500	17113	shoe leather	84.2	15.2		5.39	-22.6	8.5
SM2.3	2	Human	16831	19181	skin	65.1	48.3		3.66	-18.2	14.4
SM2.4	2	Human			hair				3.41	-18.9	11.4
SM3.1	3	Textile	17111	15030	cloth	42.2	44.1		3.65	-20.5	6.6
SM3.2	3	Textile	17114	15031	cloth	44.3	44.2		3.52	-19.7	8.5
SM3.3	3	Human	17115	15032	soft tissue	24	48.1		4.36	-20.4	13
SM4.1	4	Textile	17108	14992	cloth	12.3	36.4		3.9	-19.9	
SM4.2	4	Human	17109	15028	soft tissue	6.5	57.1		9.67	-23.1	14.7
SM4.3	4	Leather	17110	15029	fur cloak	45.2	39.1		3.57	-20.5	7.4
SM4.4	4	Human			blood?		49.5	13.27	4.35	-20.88	15.67
SM4.5	4	Human			blood?		47.83	12.86	4.34	-20.72	15.62
SM4.6	4	Human			blood?		52.3	13.78	4.43	-20.8	16.29
SM4.7	4	Human			chest tissue		68.85	5.73	14.03	-23.5	17.65
SM4.8	4	Human			chest tissue		65.76	5.62	13.63	-23.58	17.29
SM4.9	4	Human			chest tissue		72.84	4.68	18.08	-23.74	17.28
SM4.10	4	Human			underarm tissue		59.92	7.6	9.18	-23.13	15.86
SM4.11	4	Human			underarm tissue		62.46	5	14.54	-23.88	15.22
SM4.12	4	Human			underarm tissue		65.73	5.53	13.85	-23.73	16.48
SM5.1	5	Human	19182	16832	skin	54.7	48.8		5.19	-20.2	15.1
SM5.2	5	Human			hair				3.67	-18.6	10.0

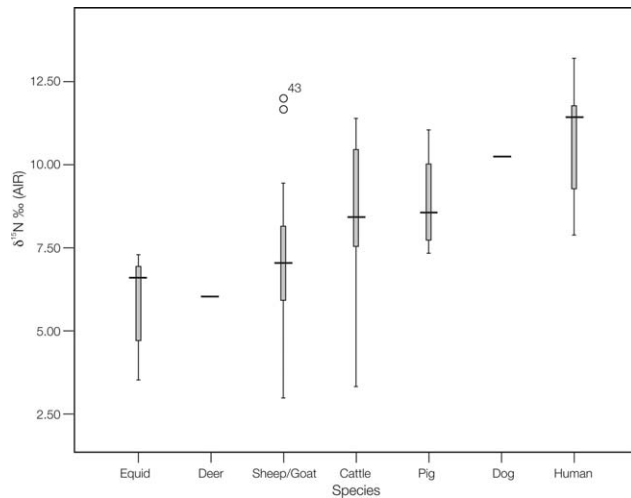


Fig. 4. Box and whisker plot of $\delta^{15}\text{N}$ for each species from Supporting Information Table S1.

Mummy no. 3 and measurements SM4.1-SM4.3 on Mummy no. 4 were made in support of radiocarbon dating of samples submitted by ICHHTO. The measurements on Mummies no. 3 and 5 were made on samples collected by one of the authors (AMP) in 2007, also used for dating. In all cases the isotopic data quoted as a by-product of radiocarbon dating are single measurements. Samples SM4.4 - SM4.12 on Mummy no. 4 were isotopic measurements made on samples collected by Mr. Abolfazl Aali of the Zanjan Cultural Heritage Organization in 2008, and these were processed in triplicate as described above. The fragmentary nature of the remains of Mummy no. 2 and the conditions of recovery make it possible that the shoe leather (SM2.2) is not directly related to the body, but it was found in close proximity. The contextual relationship of the materials found with Mummies no. 3, 4, and 5 are more certain, since they were excavated by Mr. Aali under controlled conditions. The hair samples from Mummies no. 2 and 5 were collected by AMP in 2007, and were measured by Dr A.S. Wilson, University of Bradford, UK. For Mummy no. 2 two strands of hair were combined and sampled in four 1-cm sections, but since no isotopic variation was observed along the hair shaft (see, Pollard et al., 2008; Table 2), these four values have been averaged in Table 1. For Mummy no. 5, two hairs were used, but only one 1-cm length of hair was obtainable.

DISCUSSION

The Oxford human and faunal data

Figure 4 shows a box and whisker plot of the $\delta^{15}\text{N}$ values of all the data in Supporting Information Table S1 plotted as a function of species (although Supporting Information Table S1 shows some species attributions as specifically “sheep” or “goat,” for the purposes of data interpretation we have included these simply as “sheep/goat”).

These values show the expected trophic level order for most species represented [sheep/goat (median $\delta^{15}\text{N}$ = 7.02‰) ~ equid (6.61‰) ~ deer < pig (8.57‰) < human (11.41‰) ~ dog], except that cattle appear to be higher on average and also more variable than might be expected (median $\delta^{15}\text{N}$ = 8.42‰). One value in particu-

lar is very low in $\delta^{15}\text{N}$ (Iran 63, Tübreh Rîz, cattle humerus; $\delta^{15}\text{N}$ = 3.33‰). This is the only sample of cattle bone from Tübreh Rîz, and the sheep from this site are also low in $\delta^{15}\text{N}$ (see below). The variability in cattle is confirmed by the data for $\delta^{13}\text{C}$, where Figure 3 shows clearly that three samples from Nargas Tepe, all cattle, have a significant C_4 dietary component (Supporting Information Table S1: Iran 03, cattle radius, $\delta^{13}\text{C}$ = -15.22‰, $\delta^{15}\text{N}$ = 7.43‰; Iran 05, cattle maxilla, $\delta^{13}\text{C}$ = -9.94‰, $\delta^{15}\text{N}$ = 6.59‰; Iran 08, cattle humerus, $\delta^{13}\text{C}$ = -13.54‰, $\delta^{15}\text{N}$ = 6.53‰). Nargas Tepe is in the very north of Iran, close to the Caspian Sea and the Turkmenistan border. The cattle come from three different contexts, two of which (Iran 03 and Iran 05) date to ~360 to 1 cal BC, and one of which (Iran 08) is much earlier (3650–3350 cal BC). Three other cattle were analyzed from the same site, and although they were found to be more consistent with the other cattle from Iran, they still had lower $\delta^{13}\text{C}$ than might be expected for a pure C_3 grazer ($\delta^{13}\text{C}$ = -17.41‰, -17.01‰, -16.41‰, compared with $\delta^{13}\text{C}$ = -20.09‰ and -19.19‰ for two equids from the same site, and $\delta^{13}\text{C}$ = -19.52‰ for a red or fallow deer). It looks as if three of the six cattle from Nargas Tepe (alone of those analyzed so far from Iran) have evidence for significant C_4 foddering, whereas the other three may have some limited C_4 foddering. Such a range of values is similar to that published by Copley et al. (2004) for cattle (and, in their case, also for sheep/goat) from Qasr Ibrim in Egypt. This site was occupied from c. 700 BC to 1800 AD, and an analysis of collagen from 11 cows gave a range of $\delta^{13}\text{C}$ from -16.7 to -8.6‰ and $\delta^{15}\text{N}$ from 7 to 10.5‰, compared to -17.41 to -9.94‰ and 6.53 to 8.56‰, respectively from Nargas Tepe. Copley et al. concluded that the Qasr Ibrim cattle must have consumed a mixture of C_3 and C_4 plants, with an almost totally C_4 diet, consisting of sorghum or millet, toward the end of the occupation of the site (where the range of $\delta^{13}\text{C}$ values narrows to -13.3 to -8.6‰). It is not unreasonable to suggest that some of the cattle at Nargas Tepe are being fed on a similar C_4 -rich diet, but that the diet of cattle so far analyzed from the other Iranian sites appears to be much more C_3 -based.

One further point is apparent from the faunal data shown in Figure 4. The median value of the $\delta^{15}\text{N}$ data for Iranian cattle is 8.42‰ (n = 20). The long term average for cattle from the Holocene (from c. 9000 BP), according to the summary published by Hedges et al. (2004), is typically around +6‰, and never goes above +7‰. Although not a rigorous comparison, it does suggest that the Iranian cattle are somewhat higher in $\delta^{15}\text{N}$ than the average from temperate Europe (the samples in Hedges et al. are mainly from the UK, but include northern Europe more generally, north of 45° latitude)—an impression also given by the data on humans discussed below. The Iranian equids are more consistent with, but at the high end of, the range for temperate Holocene horses published by Hedges et al. [Iranian median ~6.61‰ (n = 6), Hedges et al. range 3.5–7.5‰].

From this we suspect that the whole of the Iranian ecosystem represented by our samples is elevated in $\delta^{15}\text{N}$ compared to more temperate regions. It has been suggested elsewhere that such an elevation is a response to aridity (Schwarcz et al., 1999). Thompson et al. (2005) report cattle $\delta^{15}\text{N}$ values from three sites in the Nile Valley ranging from 6.0 to 12.9‰, and humans with a mean value of 13.2‰ \pm 1‰. Such an enrichment, they say, is

a commonly observed phenomenon in desert environments, either as a result of light NH_3 "evaporating" from the soil leaving enriched nitrogen to be taken-up by plants and animals, or from recycling of urea in animals as a response to water stress (which they suggest is less likely). In a subsequent paper (Thompson et al., 2008), concerning similarly elevated samples from Kerma in Upper Nubia (human $\delta^{15}\text{N}$ range 12.4–15.4‰) they added the third possibility of the inhibition of nitrogen-fixing bacteria in the soil.

Ecological studies of nitrogen cycling in grasslands have suggested that soil nitrogen loss increases with increasing aridity (McCulley et al., 2009), and consequently, because most nitrogen loss processes (e.g., nitrification, denitrification, and NH_3 volatilization) result in $\delta^{15}\text{N}$ enrichment in the remaining pool, soil, and subsequently foliar $\delta^{15}\text{N}$ values become more positive with increasing aridity. On a global scale, Handley et al. (1999, Fig. 1B) have shown that foliar $\delta^{15}\text{N}$ values correlate most strongly with rainfall ($\delta^{15}\text{N}_F = 4.39 - 0.003 \times \text{Mean Annual Rainfall in mm}$, $r = -0.59$), and postulated that any factor which decreases the proportional flux of nitrogen into the organic matter storage pools will enhance the $\delta^{15}\text{N}$ values in the ecosystem. Such processes, they suggest, might include "aridity, tillage, salinity, extreme pH, fire, or grazing" (Handley et al., 1999; p 193). Similar but more recent global studies have suggested that both soil and plant $\delta^{15}\text{N}$ values decrease with increasing mean annual precipitation and decreasing mean annual temperature (Amundson et al., 2003). Specific case studies, such as that of Aranibar et al. (2004) along a precipitation gradient in the Kalahari, have confirmed the inverse relationship between foliar $\delta^{15}\text{N}$ and mean annual precipitation, with a linear regression equation of $\delta^{15}\text{N}_F = 6.2722 - 0.0047 \times \text{Mean Annual Rainfall in mm}$ (Aranibar et al., 2004, Fig. 1).

Iran is one of the climatically most diverse regions in western Asia, with a correspondingly complex phyto geography, which has been thoroughly described by Zohary (1963). He identified five main floristic regions (Euro-Siberian, Irano-Turanian, Mediterranean, Saharo-Arabian, and Sudanian), the distribution of which is controlled principally by topography, soil type, and climate. Iran shows an extreme temperature range, encompassing the Alborz mountains in the north (with minimum temperatures of -20°C , and permanent snow fields on the highest mountains), to the Iranian Gulf in the south, with an annual temperature range of above 0°C in winter to around 50°C in summer. Precipitation in Iran declines substantially from north to south, and from west to east, with the Central Plateau (altitude 900–4,000 m) being essentially protected from the rain-bearing winds by the Alborz mountains in the north, the Zagros in the west, and the Makran-Laristan ridges to the south. Rainfall here is typically c. 100 mm/year, falling to c. 50 mm/year in the Dasht-e-Lut desert in the south, and the vegetation is typically Irano-Turanian. In contrast, to the north of the Alborz mountains on the Caspian plain the rainfall can reach 2,000 mm/year, supporting extensive temperate forests. Tehran, on the southern slopes of the Alborz mountains and on the threshold of the Central Plateau, has an annual rainfall of 237 mm/year. For most of the sites discussed here, the modern rainfall is likely to be below 300 mm/year, which is probably sufficient to trigger elevated $\delta^{15}\text{N}$ as a result of aridity (and possibly associated high summer temperatures) affecting the nitrogen cycle, as discussed above. Using the regres-

sion equation of Aranibar et al. (2004), the foliar $\delta^{15}\text{N}$ values in the arid regions (200–300 mm/year) of Iran should be between +5.3‰ and +4.9‰, which would indicate a $\delta^{15}\text{N}$ value in cattle grazing on such flora of around 8‰, using the accepted value of around +3‰ for trophic level enrichment, consistent with the median value for Iranian cattle of 8.42‰. There are very few direct measurements of the isotopic values in modern Iranian flora. Bocherens et al. (2000) report some measurements on plants collected near the vicinity of the archaeological sites of Sagzabad, Zagheh and Qabrestan on the Qazvin Plain (discussed in more detail below), with $\delta^{15}\text{N}$ values in the range of 2.2–6.4 ‰ [ignoring a value at 9.9‰ for *Astragalus* sp. (a legume) and -0.4 ‰ for *Avena* sp. (the oats family, which is likely to have been irrigated)]. All that can be said on the basis of these few data is that the hypothesis that the Iranian ecosystem is elevated in $\delta^{15}\text{N}$ because of the general aridity is plausible.

Comparison with other Iranian isotopic data

To more fully discuss the isotopic data of human and faunal remains from Iran, we have combined our measurements (Tables S1 and 1) with the data published by Bocherens et al. (2000, 2006). In the earlier of these two papers, they analyzed archeological material from three settlement mounds close together on the Qazvin Plain, west of Tehran—Zagheh (6th to 5th Millennium BC, Neolithic), Qabrestan (also known as Gabristan: 4th to 3rd millennium BC, Chalcolithic) and Sagzabad (2nd to 1st millennium BC, Iron Age). The animals represented consist of wild and domesticated species, but with significant numbers only of sheep/goat and humans from Zagheh (four each) and sheep/goat from Qabrestan (5). They complemented these data with a number of measurements made on modern animals collected from close to these sites (nine, of which three were sheep/goat, two donkey, and two dog, plus a fox), and also from a selection of modern plant species, as mentioned above (16, of which five were C_4 photosynthesizers; six of the 16 species have both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reported). In Bocherens et al. (2006) they reported the analyses of later material from the Dehistan Plain of southern Turkmenistan, just north of Alexander's Wall in northern Iran, and to the east of the Caspian Sea. The specific sites were Geoktchik Depe (occupied during the Iron Age, c. 1300 BC, and through the Sassanian and Early Islamic periods, c. 6th to 7th C. AD) and Misrijian, with archeological remains from the Ilkhanid (Mongol) period, c. 11th to 12th C. AD. Species represented again include wild and domesticated mammals, plus humans, but most are represented by only one or two examples. There are two humans reported from Geoktchik Depe, and one (juvenile) from Misrijian.

The combined data set allows us to study more fully the archeological isotopic data from a range of sites in Iran and neighboring Turkmenistan during the Chalcolithic to Iron Age periods. We have reasonable size datasets for cattle, sheep/goat, pigs and humans, and therefore focus on these.

Cattle. We have noted above the marked difference between some of the cattle from Nargas Tepe compared to other Iranian sites. Unfortunately the additional data only contain three further analyses of cattle bone, but these are also unusual—the two from Geoktchik Tepe have high $\delta^{15}\text{N}$ values (13.2 and 15.1‰), combined with relatively high (i.e., less negative) $\delta^{13}\text{C}$ values (-13.9

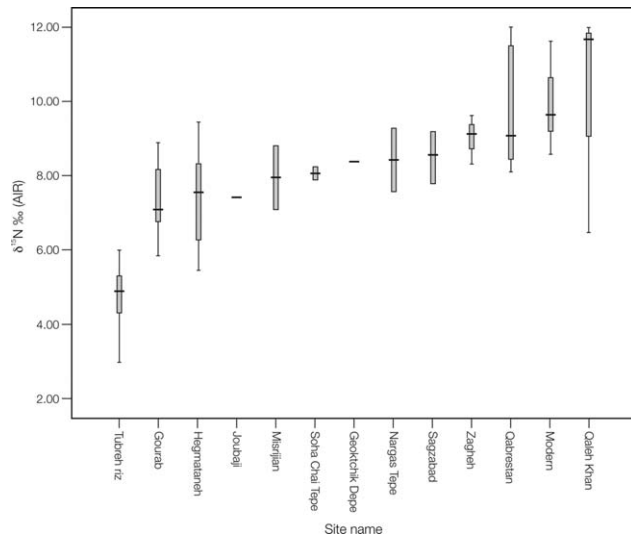


Fig. 5. Box and whisker plot of $\delta^{15}\text{N}$ for all sheep/goat samples (including data from Bocherens et al., 2000, 2006), classified by site.

and -17.1‰), whilst the single cattle bone from Misrijan has $\delta^{13}\text{C} = -16.9\text{‰}$ and $\delta^{15}\text{N} = 10.8\text{‰}$, all of which is suggestive of some C_4 dietary component, as discussed above. This observation is consistent with the relatively close proximity of these three sites on the steppe of southern Turkmenistan and northern Iran, and is indicative of significant C_4 dietary input into cattle in this region by the mid-fourth millennium BC, perhaps from deliberate foddering (probably using millet), or perhaps just as a result of selective grazing of wild C_4 flora.

Sheep/goat. The majority of the sheep/goat lie on a trend line which runs from approximately $\delta^{13}\text{C} = -20.3\text{‰}$, $\delta^{15}\text{N} = 3\text{‰}$ to $\delta^{13}\text{C} = -16.5\text{‰}$, $\delta^{15}\text{N} = 12\text{‰}$, but there do appear to be some significant differences by site, with Tübreh Rız having much lower $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ than any of the other sites, whilst Nargas Tepe has equally low $\delta^{13}\text{C}$ (median -20.93‰ , but with only two samples). A plot of the $\delta^{15}\text{N}$ values for sheep/goat by site (see Fig. 5) shows that the samples from Tübreh Rız have a median value of 4.9‰ , compared to other sites which have medians between 7.1 and 11.6‰ . The $\delta^{13}\text{C}$ values from Tübreh Rız, however, are more negative than those from any other site except Nargas Tepe (median -19.76‰), negating the possibility of C_4 foddering, and suggesting that the sheep/goat (and the single cow) from this site were not subjected to the same degree of water stress experienced by all the other fauna sampled from Iran. The reason for this is not immediately apparent. Although Tübreh Rız is located in the Zagros mountains, and therefore is likely to have had a higher average rainfall than most of the other sites, it is not far from Gourab, which exhibits the same pattern as all the other sites.

Pig. Most of the pigs (7 of 9) reported by Bocherens et al. lie between -20.7 and -19.4‰ for $\delta^{13}\text{C}$ and 12 to 13.2‰ for $\delta^{15}\text{N}$, whereas the data for three of the four measured in Oxford are lower in $\delta^{15}\text{N}$ (c. 8‰), and are on average slightly less negative in $\delta^{13}\text{C}$ (-20.3 to -18.9‰). It is perhaps significant that Bocherens et al. describe most of their suid samples as wild boar, whereas the Oxford samples are labeled “pig” (implying

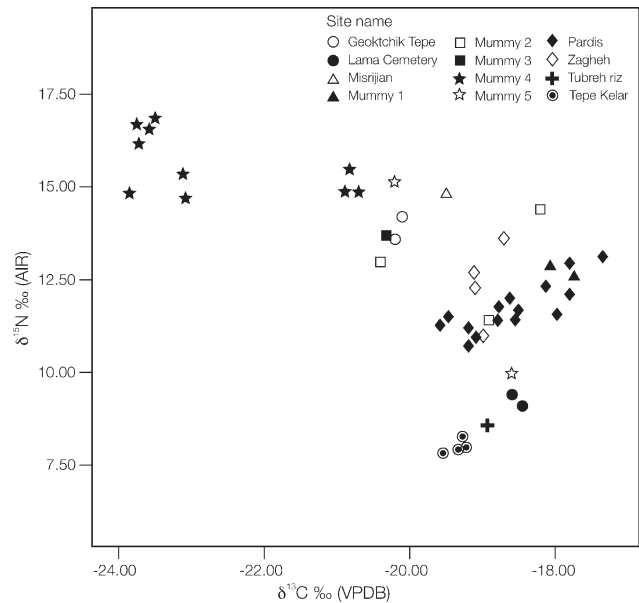


Fig. 6. Plot of isotopic data obtained on all human tissue from Supporting Information Tables S1 and 1, and from Bocherens et al. (2000, 2006).

domesticated pig). No attempt was made to distinguish wild from domesticated pig because of the difficulties of doing so on small fragmentary bone samples—such distinctions are usually based on overall size. Having said that, there was nothing seen by the bone specialist (JH) which would suggest wild rather than domesticated pig, and it may therefore be that the isotopic differences observed above are indeed due to domestication.

Equid. The equids cover a large range of isotopic values, from -19.2 to -15.9‰ in $\delta^{13}\text{C}$ and 3.5 to 12.4‰ in $\delta^{15}\text{N}$. It is striking that the data reported by Bocherens et al. tend to be higher in $\delta^{15}\text{N}$ (above 9‰) and slightly less negative in $\delta^{13}\text{C}$ (higher than -19‰), and, in one modern donkey, as high as -15.9‰ . These samples are either identified as donkey or hemione (equus), whereas the Oxford samples are more generically labeled as equid. Again, we made no attempt to distinguish between horse, donkey or hemione because of the fragmentary nature of the bone assemblage, but the impression obtained during sorting was that the samples probably came from domesticated horse. It is possible that some of the animals measured by Bocherens et al. (especially the modern donkey) were foddered with plant material containing a C_4 component, but the horses reported in Table S1 appear to occupy the same niche as the sheep/goat, with little or no C_4 foddering.

The human and “mummy” data. The most significant comparisons to be made are on the isotopic data for the humans from various sites, compared to the values obtained from the salt-preserved “mummies” at Chehr Abad salt mine. Figure 6 shows all the data obtained on human material from Supporting Information Tables S1 and 1, and from Bocherens et al. (2000, 2006). The data for the Chehr Abad remains are differentiated according to “mummy,” but not by tissue type—this has been shown in Table 1.

It is clear that the majority of the samples from Mummy no. 4 are significantly differentiated from any

other material so far reported—principally by being extremely depleted in $\delta^{13}\text{C}$ (c. -23%), and high in $\delta^{15}\text{N}$ (above 15%). The three samples from Mummy no. 4 which do not conform to this pattern were labeled "blood" and have no carbon or nitrogen yield reported but a C/N ratio of around 4.4. We assume that these are either contaminated, or are not representative of the long-term isotopic values for this body. Since only the two re-measurements of the collagen samples from Mummy no. 1 reported here for the Chehr Abad humans are from bone collagen, we discuss below the likelihood of isotopic offsets between different preserved tissues.

The remaining human isotopic data (i.e., not including the mummies) appear to fall into three groups by site, which seems to have some geographical or ecological significance:

- i. Tepe Kelar, Tübreh Rîz, and Lama Cemetery
- ii. Tepe Pardis and Zagheh
- iii. Geoktchik Depe and Misrijian

Group i) is characterized by lower $\delta^{15}\text{N}$ values (below 10%) and $\delta^{13}\text{C}$ values of around -19% . Tübreh Rîz and Lama Cemetery are located in the Zagros mountains to the south and east of Iran, whilst Tepe Kelar is in the Alborz mountains north of Tehran. It is possible that these three sites, although not closely related geographically, have a similar mountainous ecosystem. Although one of the two measurements from Mummy no. 5 falls into this region, Table 1 shows this to relate to the hair rather than the tissue sample, and is not, therefore, strictly comparable to the bone collagen measurements.

Group ii) consists of humans from Tepe Pardis and Zagheh—both of which are settlement mounds in semi-arid plains, one to the east of Tehran and one near Qazvin to the west. They are, however, widely separated in time—Zagheh is attributed by Bocherens et al. (2000) to the Neolithic (c. 6th to 5th millennium BC), whereas, although Tepe Pardis was also occupied in this period (see Fig. 2), the human skeletons reported here are dated to the 2nd millennium BC. Two of the three measurements reported on Mummy no. 2 are associated with this group, making it tempting to conclude that Mummy no. 2 could have come from the northern plains of Iran, but it is important to note that these two measurements are on skin and hair (collected by AMP in 2007), whereas the third is an older measurement on "soft tissue," and is more closely associated to group iii). However, both of the re-measurements made on the bone from Mummy no. 1 are closely associated with this group (in fact, they are indistinguishable from the samples from Tepe Pardis, even though the "salt man" postdates these remains by about 2,000 years).

Group iii) is defined by the three samples of human bone published by Bocherens et al. (2006), from the Dehistan Plain of southern Turkmenistan. Associated with these three points are the single soft tissue measurements from Mummy no. 3 and 5 (but as noted above the hair from no. 5 is also with Group i), and the soft tissue measurement from Mummy no. 2 (but other measurements are with Group ii).

The measurements reported on the Chehr Abad salt-preserved human tissue are, with the exception of some of the measurements made on Mummy no. 4 and the new remeasurements made on Mummy no. 1, not ideal for isotopic comparison with the rest of the data set. They are mostly not on bone collagen, and were incident-

tal measurements made as part of a radiocarbon measurement program on soft tissue samples submitted from Iran. One key question which must be addressed before any firm conclusions can be drawn about the origin of these mummies is "how well can we compare the data on measurements of human tissue with those from bone collagen?" Although all such measurements (except hair) are ultimately made on extracted collagen, it is possible that differences might occur because of preferential routing or rates of manufacture of amino acids in different tissues, or, perhaps more likely, because of different collagen turnover rates— for bone this is on the order of several years, but for skin only around 15 days. Isotopic differences between bone and skin collagen might therefore be expected if the diet in the last couple of weeks of life was extremely different to the long-term average. The same consideration would also apply to isotopic measurements on hair keratin, which also records the last few months of life.

The literature is somewhat ambiguous as to whether such differences can be observed in mummified tissue. White and Schwarcz (1994; p 178) reported that the average difference was -0.17% in $\delta^{13}\text{C}$ and $+1.71\%$ in $\delta^{15}\text{N}$ between the isotope values for skin compared to bone ($\Delta = \delta_{\text{skin}} - \delta_{\text{bone}}$) in a number of naturally desiccated Nubian male mummies dating between 350 BC and AD 1400, but -0.24% in $\delta^{13}\text{C}$ and $+2.69\%$ for $\delta^{15}\text{N}$ for females (typically 30 measurements of bone and 15 of skin for each of the male and female groups, but not reported as matched pairs). Others have reported much larger differences when comparing skin and bone from the same mummy. Iacumin et al. (1996; p 20–21) reported analysis of bone and skin from three mummies from Egypt in the collection of the Museum of Natural History, Trieste, but two were undated and all unprovenanced. $\Delta_{\text{s-b}}$ values for these are -0.6 , -2.6 , and -1.1% for $\delta^{13}\text{C}$ and $+4.9$, $+3.3$, and $+2.6\%$ for $\delta^{15}\text{N}$ (giving an average of -1.4% for $\delta^{13}\text{C}$ and $+3.6\%$ for $\delta^{15}\text{N}$). In a later paper on the Kerma necropolis in ancient Nubia (c. 2500 to 1500 BC), Iacumin et al. (1998; p 299) report the $\Delta_{\text{s-b}}$ differences in five naturally-preserved mummies as $+4.8$, $+1.2$, -2.6 , $+2.5$ and $+0.7\%$ (av. = $+1.3\%$) for $\delta^{13}\text{C}$ and -2.6 , $+4.4$, $+2.4$, $+4.8$, $+5.8\%$ (av. = $+3.2\%$) for $\delta^{15}\text{N}$.

It is difficult to draw firm conclusions from such disparate observations, since some results are on naturally- and others on artificially-mummified remains (which might be expected to affect the skin chemistry), nor is there any theoretical reason to expect that $\Delta_{\text{s-b}}$ should show a consistent pattern between individuals or groups of individuals. The magnitude and the direction could be dictated purely by dietary differences between long-term and immediately premortem diets. Nevertheless such observations counsel caution when comparing isotopic measurements on bone with skin or other preserved soft tissue. They suggest that differences between measurements on skin and bone from the same individual could differ by $\pm 1.5\%$ in $\delta^{13}\text{C}$ and perhaps as much as $\pm 3.5\%$ in $\delta^{15}\text{N}$ (although for $\delta^{15}\text{N}$ the differences appear to be more consistently positive, i.e., the skin values are usually more positive than those from bone), which might explain why the values reported in Table 1 for the human remains from Chehr Abad are somewhat higher in $\delta^{15}\text{N}$ (median = 15.4%) than the measurements on archeological bone collagen (typically between 7.5 and 15%).

Returning to our primary research questions of "how was the site exploited—who was doing the mining, what

was the socio-economic context of the mine, and where was the salt traded," we can begin to make progress. We may chronologically separate mummies no. 1 and 2 from mummies no. 3, 4, and 5 as the former fall between the fourth and sixth centuries AD whilst the latter tightly cluster between 410 and 350 BC (Pollard et al., 2008; p 137–142). The three earlier Mummies lie firmly in the middle of the Achaemenid period within the reigns of Darius II (r. 423 BC to 404 BC) and Artaxerxes II Memnon (r. 404–358), a junction which saw the empire close to its geographical zenith stretching from Indus in the east to the Nile and shores of the Aegean in the west. Linked by the Royal Road, the satrapies of east and west brought tribute and taxes to the Achaemenid heartlands as physically depicted on the great east staircase of the Apadana at Persepolis where Gandharans, Indians, Armenians and Assyrians with their bulls, rams and camels rub shoulders with Medes and Persians (Curtis, 2000). More than mere propaganda, the Royal Road, common script and central administration facilitated vast mobility within the empire as slaves, conscripts and tribute were drawn from individual satrapies and redistributed making the presence of non-local individuals in Zanjan far from unexpected. The depiction of the empire's 23 subject peoples bringing tribute to Persepolis is corroborated by its textual sources which record the tributes and taxes to be paid, taxes which also included salt (Frye, 1963). Indeed, cuneiform tablets record the presence of a thriving urban trade in "salt, beer, wine, and ceramic vessels" (Dandamaev and Lukonin, 1989; p 215), underlining its importance as both a staple as well as an item of economic desirability.

Salt's key economic and staple value centers on its use as the main preelectrical method for preserving meat either through the direct application of salt or salt in solution. Both techniques inhibit microbiological growth and discourage insects from feeding on raw surfaces and laying eggs due to the hypertonic nature of salt. Used to preserve meat domestically as well as by the state, salt's hypertonic nature also allowed it to be used as a weapon of mass destruction as documented by the Babylonian ruler Ashurbanipal, who records that having opened the treasuries and destroyed the temples of Susa in western Iran, he then slaughtered their livestock and salted their fields in 639 BC (Curtis, 2000). With salt thus at a premium within the empire, it should be no surprise that individuals from peripheral areas within the empire were prepared to move (or be moved) to facilitate its extraction. However, one of our main problems with understanding or reconstructing the social and economic role of this Achaemenid salt mine is the lack of comparable examples of a contemporaneous nature, forcing us to focus on the models of mass coercion associated with the Greco-Roman world as optimized by Lavrion. Indeed, despite being a key staple in the ancient world there are only two other excavated salt extraction sites, the later Iron Age working at Kibiro on the banks of Lake Albert in Uganda (Connah, 1996) and the Iron Age cuttings at Dürrenberg in Austria (Megaw et al., 2000; Boenke, 2005). Of these, only the latter was engaged with digging deep shafts whilst the former focused on surface workings but, importantly, neither appears to have been associated with coercive behavior, rather they are examples of economic specialization and adaptation.

However unique, the presence of subsurface salt workings at this period in Iran should not be a surprise either as the practice of mining was already well devel-

oped within the empire. Although intermittent copper mining within the central plateau has an antiquity of at least the fourth millennium BC as identified at Veshno-veh near Qom (Pigott, 1999; p 78), Moorey acknowledges a vast increase in ore extraction in response to Achaemenid demand (1994). Miners, and those involved with ore extraction, represent only one section of the professional teams, active within the Achaemenid world. The period is also associated with the development and spread of qanat technology, with some scholars suggesting that "qanats emerged as an offshoot of the ancient mining industry in the region... Expertise in tunneling was readily transferable, and miners unintentionally tapping into underground streams" (Burke and Pomeranz, 2009; p 86). This is quite possible as qanats are subterranean canals which feed ground water from a "mother well" or aquifer on piedmont out to settlements and fields in the arid plains up to 50km away. Excavated by specialist *muqanni*, the qanat canals are between 70 and 90 m below the ground surface and are linked by a series of vertical shafts for both initial construction and occasional maintenance (Beaumont et al., 1989).

CONCLUSIONS

On the basis of the current data (and emphasizing the difficulties of comparing the data from bone collagen with other tissue), it is tempting to conclude that, of the five salt-preserved human "mummies" from Chehr Abad, Mummy no. 4 is a complete outsider, Mummies no. 1 and 2 could have come from the northern plateau of Iran (the Tehran or Qazvin Plains), and Mummies no. 3 and 5 may be from further away in the more arid steppes of north-eastern Iran into Central Asia. The best of these associations is in fact that for Mummy no. 1, which, based on the re-measured bone collagen values, is isotopically identical to the humans reported from Tepe Paridis (and, incidentally, assuming that one measurement is from the leg and one from the head, are sufficiently similar to support the original view that they are both from the same body).

It appears as if the entire prehistoric Iranian ecosystem (as represented by the samples published here) has elevated $\delta^{15}\text{N}$ values compared to more temperate ecosystems. Such elevations have been documented elsewhere in other arid or semi-arid archeological regions (e.g., the Nile Valley and Sudan), and has been attributed to a complicated interaction between aridity and the rate of nitrogen cycling and fixation, resulting in higher $\delta^{15}\text{N}$ values in plant material at the base of the food chain. An exception appears to be the sheep/goat and (single) cow from Tubreh Riz in the Zagros mountains, which for some reason do not seem to have suffered from the same level of water stress.

Focusing on cattle, we have observed the presence of some cattle with a significant component of C_4 dietary input at Nargas Tepe, which conforms to the pattern already noted by Bocherens et al. (2006) in nearby Turkmenistan. Again, this is a phenomenon observed in other parts of North Africa and Western Asia, and attributed to the inclusion of millet or sorghum in the fodder. At Qasr Ibrim, in southern Egypt, for example, Copley et al. (2004) have identified mixed C_3/C_4 foddering from 700 BC onward (the earliest material examined from that site), with increased C_4 input from c. 500 AD. Millet is thought to have been domesticated from a wild progenitor somewhere between the Caspian Sea and Mongo-

lia, and some of the earliest evidence comes from Tepe Yahya in Iran during the 5th millennium BC (Zohary and Hopf, 2000). It spread from the Steppes into Central and Eastern Europe during the Neolithic period and C₄ input into human and animal bone has now been recorded in Bronze Age northern Italy (c. 16th to 12th C. BC; Tafuri et al., 2009). It would appear that at least one bovid at Nargas Tepe in northern Iran was being foddered using significant quantities of C₄ plants (almost certainly millet) by the mid-fourth millennium BC. Sheep/goat, on the other hand, shows less evidence for C₄ foddering at any site in Iran. Compared with the data from Copley et al. (2004) for sheep/goat from Qasr Ibrim, where the $\delta^{13}\text{C}$ values range from -20.0 to -10.2‰ (which they attribute to mixed C₃/C₄ foddering), the Iranian values do not go above -16.6‰ , suggesting that such practices were much less prevalent in Iran.

Although the full report on the miners, the mines and their associated artifacts has yet to be completed, an initial review of the archeological record associated with the bodies provides support for the hypothesis that these "miners" had traveled some distance to collect salt. Although not yet entirely consistent, there appears to be a good chance that a picture of where these people came from may emerge from further study of the material remains and the bodies themselves (especially if we are able to obtain bone and tooth samples from the "mummies") which will provide us with an almost unique opportunity to study issues of mobility and redistribution in one of the largest empires of the ancient world.

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